CRUSTACEAN ZOOPLANKTON IN LAKE ERIE OFF CLEVELAND HARBOR[1]

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Abstract. Zooplankton samples were collected from 5 stations in Lake Erie off Cleveland Harbor in June, August, and November 1973 and April 1974. Identification of 26 zooplankton groups was made, the most common being (in decreasing order of abundance) copepod nauplii, bosminids with mucro, immature cyclopoid copepodids, *Eubosmina coregoni*, *Daphnia retrocurva*, *Cyclops bicuspidatus thomasi*, immature calanoid copepodids, *Daphnia galeata mendotae*, *Cyclops vernalis*, *Ceriodaphnia lacustris*, *Mesocyclops edax*. Crustacean zooplankton were most abundant in June (158,000/m^3) and least abundant in November (27,600/m^3). Cladocerans were dominant only in August. Nauplii accounted for 82% of all zooplankton in April. Comparison of the seasonal abundance of immature dipatomid copepodids suggests that breeding seasons were probably similar in the 1950's and 1970's. It appears that the crustacean zooplankton community off Cleveland Harbor probably has not changed significantly since the mid-1950's.

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There have been numerous studies of zooplankton in various parts of Lake Erie, but only 3 quantitative studies in the area off Cleveland Harbor (Davis 1954, 1962; Rolan *et al* 1973). Davis' (1954) first study was from September 1950 to September 1951 at 6 stations along the breakwater and 2 extending lakeward from the western end of the breakwall. The second study (Davis 1962) was from September 1956 to October 1957 at 3 stations in a transect perpendicular to shore at the western end of the breakwall. From September 1971 to November 1972, Rolan *et al* (1973) sampled zooplankton at 10 stations along the Cleveland shoreline.

The present study adds to knowledge of crustacean zooplankton in Lake Erie off Cleveland Harbor and includes the enumeration of calanoid copepodids to species for each life history stage. Complete copepodid identification is important, and long overdue, because the younger forms probably occupy different niches from the adults (Czaika 1974) and because distributional analyses are incomplete when only the last of 12 life history stages is used.

METHODS AND MATERIALS

Zooplankton samples were collected from 5 stations in Lake Erie off Cleveland. Their coordinates, distances from shore in km, and depths in meters were as follows: station 115: 41°36′55″N, 81°47′0″W, 13.68 km, 18.3 m; station 155: 41°34′12″N, 81°44′12″W, 7.24 km, 16.8 m; station 172: 41°31′15″N, 81°45′29″W, 4.02 km, 13.0 m; station 195: 41°32′12″N, 81°41′18″W, 1.21 km, 8.5 m; station 197: 41°32′30″N, 81°39′30″W, 1.61 km, 11.8 m. All stations were outside the breakwall. Sampling dates were June 13–19, August 21–23, November 18–December 1, 1973 and April 17, 1974. Vertical net hauls were made from just off bottom to the surface with a 0.5 m, 64 μ mesh (#25) plankton net. The samples were subsampled by pipette. A minimum of 200 non-naupliar crustaceans was counted in accordance with Patalas (1969), Czaika (1974), and Watson and Carpenter (1974). In addition, copepod nauplii were enumerated as a single identification group. Terminology used to designate copepod stages was as follows: nauplii: the first six stages, NI–NVI; copepodids: the last six stages, CI–CVI; adults: the last copepodid stage, CVI; immature copepodids: the non-adult copepodids, CI–CV.

Calanoid copepodids (CI–CVI) were identified to species, stage, and sex using the methods of Czaika and Robertson (1968) and Czaika (1974, 1976). Immature cyclopoid copepodids (CI–CV) were split into 2 groups, those with 2

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or 3 pairs of swimming legs (CI–CII) and those with at least 4 pairs of legs (CIII–CV). Adult cyclopoids and non-diaptomid calanoids were identified using the key by Wilson and Yeatman (1959).

Cladocerans were identified to species except bosminids with mucro (mucronate) which were saved for species identification at a later date. The taxonomy of bosminids with mucro has been uncertain (Watson 1974). Non-mucronate bosminids were called *Eubosmina coregoni* according to Deevey and Deevey (1971). The Brooks (1957) key was used for identifying *Daphnia* spp. and Brooks (1959) for the rest of the cladocerans.

Concentrations of animals (numbers/m^3) were calculated from direct counts of animals captured, assuming a sampling efficiency of 100%. The actual filtration efficiency of a plankton net, however, exhibits a curvilinear decrease as the net is hauled to the surface and efficiency can drop to as low as 15–30% (McNaught *et al* 1975).

RESULTS

Seasonal Distribution. The greatest concentration of total crustacean zooplankton occurred in June when 158,000/m^3 were present (table 1). Zooplankton decreased to 110,000/m^3 by August and to 27,600/m^3 by November. In April of the following year (1974) there were nearly 1.8 times more zooplankton (47,300/m^3) than in November. The zooplankton represented 26 identification groups including the 4 juvenile copepod categories of nauplii and immature calanoid, cyclopoid, and harpacticoid copepodids.

Nauplii accounted for 82% of all crustacean zooplankton in April indicating a high level of copepod reproduc-

TABLE 1

Mean concentration (numbers/m^3) of crustacean zooplankton from 5 stations during each of 4 sampling periods in Lake Erie off Cleveland Harbor from June 1973 through April 1974.

Group and Developmental Stage	June**	Aug.	Nov.-Dec.	Apr.	Entire Study Aver.	Entire Study %
Bosminids With Mucro	26641	37329	4576	433	17245	20.11
Ceriodaphnia lacustris	—*	3759	17	—	944	1.10
Chydorus sphaericus	—	458	563	18	260	0.30
Daphnia galeata mendotae	2012	3080	41	—	1283	1.50
Daphnia longiremis	585	56	—	—	160	0.19
Daphnia retrocurva	12640	12294	280	17	6308	7.35
Diaphanosoma leuchtenbergianum	212	1487	—	—	425	0.50
Eubosmina coregoni	14966	11554	2944	750	7554	8.81
Holopedium gibberum	—	29	—	—	7	<.01
Leptodora kindtii	—	102	—	—	26	0.03
Copepod Nauplii NI–NVI	47676	23360	7436	39035	29377	34.25
Immature Calanoid Copepodids CI–V	3024	1675	342	216	1314	1.53
Diaptomus ashlandi CVI	268	28	—	220	129	0.15
Diaptomus minutus CVI	396	—	—	204	150	0.17
Diaptomus oregonensis CVI	1344	660	82	75	540	0.63
Diaptomus sicilis CVI	—	—	—	155	39	0.05
Diaptomus siciloides CVI	544	147	—	10	175	0.20
Eurytemora affinis CVI	—	—	—	—	—	—
Limnocalanus macrurus CVI	—	—	—	—	—	—
Immature Cyclopoid Copepodids CI–V	38626	11972	8993	3200	15698	18.30
CI–CII	10756	5499	4026	2329		
CIII–CV	27871	6474	4967	871		
Cyclops bicuspidatus thomasi CVI	4426	521	1192	2881	2255	2.63
Cyclops vernalis CVI	3159	142	480	7	947	1.10
Mesocyclops edax CVI	1177	1534	—	21	683	0.80
Tropocyclops prasinus mexicanus CVI	52	273	614	65	251	0.29
Immature Harpacticoid Copepodids CI–V	—	—	—	7	2	<.01
Canthocamptus robertcokeri CVI	—	—	—	11	3	<.01
Total Crustacean Zooplankton	157749	110461	27559	47318	85772	100.00

*Dash indicates none found.

**See Methods and Materials for precise dates.

tion in the spring (fig. 1). Although nauplii only comprised 30% of total zooplankton in June, they were more concentrated than in April (table 1). Even in November, copepod reproduction was still occurring with 27% of total zooplankton being nauplii.

the most abundant adult cyclopoid. It was present in fairly high numbers in June (4430/m^3), declined to 12% of this concentration by August, then was present at 27% and 65% of the June level in November and April, respectively (table 1). *Cyclops vernalis*, the second most

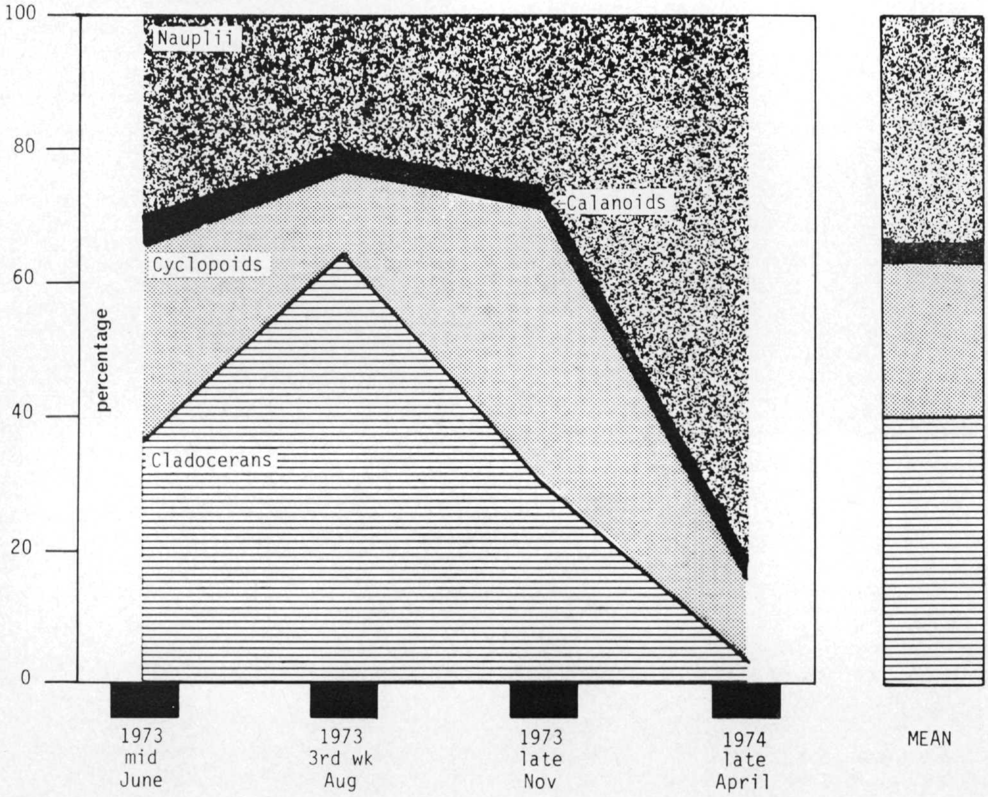

FIGURE 1. Seasonal abundance of cladocerans, cyclopoid copepodids (CI–CVI), calanoid copepodids (CI–CVI), and copepod nauplii (NI–NVI) each expressed as percentage of total zooplankton in Lake Erie off Cleveland Harbor.

Cyclopoid copepodids (CI–CVI) comprised 23% of the zooplankters during the 4 sampling periods (fig. 1). Immature cyclopoid copepodids (CI–CV) were 4 to 5 times more numerous than adults (CVI) in 1973, but in April 1974 they were only slightly more common than adults. The spring generation of cyclopoids in 1974 was apparently more or less synchronous and relatively few had reached the copepodid stage of development; nearly 75% of those that had were early copepodids (table 1).

Cyclops bicuspidatus thomasi CVI was abundant adult cyclopoid, was also moderately abundant in June (3160/m^3), then experienced a marked population decrease. In April it was present at a low level only at station 172. In August, no *Cyclops* spp. adults were detected at several stations. The distribution of *Mesocyclops edax* adults was erratic. They were not present at station 172 in June, at stations 195 and 197 in August, at 4 stations in April, or at all in November. They were the most abundant cyclopoid species, however, at station 115 in June and at station 155 in June and August.

Tropocyclops prasinus mexicanus adults increased in numbers from mid-summer to November and were at low levels again in the spring. There were no adult cyclopoids at station 197 in August.

Calanoid copepodids (CI–CVI) comprised 2–4% of the total crustacean zooplankton (fig. 1). Adults of 5 species, all diaptomids, were encountered (table 1). There were immature copepodids of those species plus *Eurytemora affinis* and *Limnocalanus macrurus* (table 2). There was only one *L. macrurus* found, a CIII in April at station 115. *E. affinis* CI, CII, CIII were present in June and CI–CV in November (table 2). Judging from Stewart's (1974) and Evans' (1975) studies of a nearshore area of southeastern Lake Michigan and Czaika's unpublished data from southwestern Lake Ontario, it is surprising that *E. affinis* immature copepodids were not detected in August.

TABLE 2

Mean concentration (numbers/m³) of each copepodid stage of 6 calanoid species from 5 stations during each of 4 collection periods in Lake Erie off Cleveland Harbor from June 1973 through April 1974.

Species–Stage		June ♂	June un.	June ♀*	Aug. ♂	Aug. un.	Aug. ♀	Nov.-Dec. ♂	Nov.-Dec. un.	Nov.-Dec. ♀	Apr. ♂	Apr. un.	Apr. ♀	Aver.
D. ashlandi	CI		13			—**			—			—		
	CII		—			—			—			—		
	CIII		38			—			—			—		
	CIV	183		177	—		—	—		—	—		—	
	CV	38		25	—		—	—		—	—		—	
	CVI	101		167	—		28	—		—	97		123	
TOTAL			742			28			—			220		248
D. minutus	CI		65			—			—			—		
	CII		99			—			—			—		
	CIII		151			—			—			—		
	CIV	—		—	—		—	—		—	—		—	
	CV	—		—	—		—	—		—	—		—	
	CVI	107		289	—		—	—		—	79		125	
TOTAL			710			—			—			204		229
D. oregonensis	CI		206			720			14			—		
	CII		273			290			—			—		
	CIII		180			92			—			—		
	CIV	64		63	—		85	—		—	—		—	
	CV	136		252	158		68	36		—	—		—	
	CVI	755		589	277		383	12		70	45		30	
TOTAL			2518			2073			132			75		1200
D. sicilis	CI		—			—			—			153		
	CII		—			—			—			19		
	CIII		—			—			—			25		
	CIV	—		—	—		—	—		—	8		—	
	CV	—		—	—		—	—		—	—		—	
	CVI	—		—	—		—	—		—	82		73	
TOTAL			—			—			—			361		90
D. siciloides	CI		416			131			—			—		
	CII		328			51			—			—		
	CIII		—			—			12			—		
	CIV	31		—	—		51	—		—	—		—	
	CV	31		52	—		28	—		—	—		—	
	CVI	94		450	119		28	—		—	10		—	
TOTAL			1404			409			12			10		459
E. affinis	CI		99			—			43			—		
	CII		52			—			99			—		
	CIII		52			—			75			—		
	CIV	—		—	—		—	—		26	—		—	
	CV	—		—	—		—	26		12	—		—	
	CVI	—		—	—		—	—		—	—		—	
TOTAL			203			—			280			—		121

*Males, no sex and females.
**Dash indicates none found.

If immature copepodids had not been identified to species, and they usually are not, the existence of this breeding population of *E. affinis* might have gone undetected.

Immature diaptomid copepodids (CI–CV) were present during all 4 sampling periods (table 2). Four species, *D. ashlandi*, *D. minutus*, *D. oregonensis*, and *D. siciloides*, were represented by copepodids of most stages in June. In August there were immature copepodids of *D. oregonensis* and *D. siciloides*. In November there were a few immature copepodids of the same species. Only *D. sicilis* had immature copepodids in April, which was the single month in which this species was observed. The pattern of immature copepodids is generally what one would expect if breeding occurred in 1973–74 as described by Davis (1961). Two deviations, noted in 1973–74, were the lack of *D. ashlandi* CI–CV in August and fewer *D. oregonensis* and *D. siciloides* CI–CV in November.

Cladocerans were dominant only in August, comprising 64% of the total crustacean zooplankton (fig. 1). There was also a high concentration of cladocerans in June (57,000/m^3), although because of even higher concentrations of copepods, their proportion of all zooplankton was 36%. By November cladocerans declined to 12% of their August level and by April they had decreased to 2%. Thus, there is good evidence of the typical cladoceran pattern of absence or low levels in winter and spring, peak concentrations in summer and declining populations through late fall.

Bosminids comprised 72% of the cladocerans (table 1). Mucronate bosminids were dominant and were probably the commonly reported *Bosmina longirostris*, but perhaps there were one or more other species, including maybe some *Eubosmina coregoni* (Wilson *et al* 1976). Bosminids with mucro were already abundant when sampling began in June (table 1). They increased about one and a half times from June to August, then decreased to 12% and 1.2% of the August level in November and April, respectively. *Eubosmina coregoni* showed a continuous decline from June to April. *Daphnia retrocurva* densities remained about the same from June to August then dropped to 2% of the August level by November. In April *D. retrocurva* was barely detectable at one station (195).

Spatial Distribution. Total zooplankton was fairly evenly distributed among the 5 stations, ranging from 18% at station 155 to 23% at station 195 (table 3). Nauplii and *Eubosmina coregoni* exhibited similar patterns to total zooplankton. Bosminids with mucro were more concentrated at the 3 stations closest to shore, while the 3 daphnid species showed a preference for the deeper stations. *Mesocyclops edax* CVI also was more common at the 2 deeper stations. *Cyclops vernalis* CVI occurred primarily at the 2 shallowest stations. *Cyclops bicuspidatus*

TABLE 3

Percentages of crustacean zooplankton from the entire study occurring at each of the 5 stations.

Identification Group	Station				
	115	155	172	195	197
Bosminids With Mucro	11	14	22	28	25
Daphnia galeata mendotae	49	34	7	3	6
Daphnia longiremis	29	29	10	15	16
Daphnia retrocurva	31	26	18	13	11
Eubosmina coregoni	19	20	20	24	17
Copepod Nauplii	19	19	22	20	20
Cyclops bicuspidatus thomasi CVI	16	13	21	38	13
Cyclops vernalis CVI	3	2	9	39	47
Mesocyclops edax CVI	35	44	2	7	11
Tropocyclops prasinus mexicanus CVI	20	3	29	38	10
Total Crustacean Zooplankton	19	18	19	23	21

thomasi CVI and *Tropocyclops prasinus mexicanus* CVI were most abundant nearest the river, at stations 172 and 195. With the exception of 2 rare cladocerans, *Holopedium gibberum* and *Leptodora kindtii*, all identification groups were present at all stations at least once during the study.

DISCUSSION

Differences in numbers of cladoceran species reported in the 3 past studies of the Cleveland area of Lake Erie and the present one are largely a matter of the identification of more daphnids and rare benthic-littoral species in the 1956–57 (Davis 1962) and 1971–72 (Rolan *et al* 1973) studies. The cladocern species lists for the 1950–51 study (Davis 1954) and the present study are similar in number, but the composition reflects recent taxonomic developments for the bosminids and daphnids. *Holopedium gibberum* was not encountered in the 3 earlier studies.

Several differences in numbers of species of adult copepods are evident among the 4 studies. It is most probable that Davis' (1954) *Cyclops americanus* and the *Cyclops vernalis* reported in the other 3 studies are the same species. *Cyclops (Acanthocyclops) vernalis* Fischer 1853 is extremely variable (Yeatman 1944, Price 1958, Reed 1970, 1971) and hence has acquired a confusing taxonomic history. Yeatman (1944) lists 22 synonyms including *C. americanus* Marsh 1893. Davis has been so thorough in up-dating his species names after taxonomic developments occur in the literature (e.g. bosminids in Davis (1968, 1969), *Mesocyclops leuckarti* and *Canthocamptus staphylinoides* in Davis (1962), *Daphnia longispina* in Davis (1968)) that it was confusing when he (Davis 1962) stated flatly that *C. vernalis* was not recognized in his earlier study (Davis 1954).

Limnocalanus macrurus was not encountered after 1951 (Davis 1954) except for one CIII in the present study. Gannon and Beeton (1971) have reported that *L. macrurus* was rare in Lake Erie by 1957, was not taken in extensive sampling in 1967, and was extremely rare in 1968. Watson and Carpenter (1974) found both adults and juveniles in low numbers in unspecified parts of Lake Erie during much of 1970, but Watson (1976) concludes that probably *L. macrurus* can not currently survive as a resident population in the Central Basin because of summer hypolimnetic anoxia.

As expected, *Eurytemora affinis* occurred in both 1971–72 (Rolan *et al* 1973) and 1973–74 but not in the earlier studies. Only Davis (1954) did not find *Tropocyclops prasinus mexicanus*. *Epischura lacustris* was absent only in the present study and Rolan *et al* (1973) encountered 3 littoral or benthic-littoral species that the others did not. The seasonal distributions of *Cyclops bicuspidatus thomasi* CVI, *Mesocyclops edax* CVI, immature cyclopoid copepodids, *Chydorus sphaericus*, and *Diaphanosoma leuchtenbergianum* generally did not vary among the 4 studies.

Several major species exhibited somewhat different seasonal abundance patterns in 1973–74 than in previous years. The most important differences occur with bominids. Because Davis' (1954, 1962) studies pre-dated the work of Deevey and Deevey (1971), he did not recognize *Eubosmina coregoni*. He reported late spring and fall maxima for *Bosmina longirostris*. In 1971–72 (Rolan *et al* 1973) *E. coregoni* was the dominant cladoceran; *B. longirostris* was the fourth most abundant cladoceran. Both species were present at low levels as expected in spring and at high levels during summer and fall. In the present study the mucronate bosminid complex was the dominant cladoceran while *E. coregoni* was second most abundant. It appears that both groups differed from the fall distribution of 1971–72 (Rolan *et al* 1973) by declining markedly, although the limited sampling regime in fall 1973 precludes a more definitive analysis.

There were differences among seasonal abundances of the daphnids. Davis' (1954) work came before Brooks' (1957) major taxonomic treatment of *Daphnia*. Davis (1968) felt the animals he reported earlier as *D. longispina* were probably *D. galeata mendotae;* they were most abundant in September of the 1950–51 and 1956–57 studies (Davis 1954, 1962). *D. galeata mendotae* was the second most important cladoceran in 1971–1972 (Rolan *et al* 1973), whereas it was the fourth most abundant cladoceran in the present study. In the 1971–72 study it occurred at moderate concentrations from September through December 1971 and was dominant from June through December 1972. Its seasonal pattern in the present study agrees more closely with the Davis (1954, 1962) findings. *D. retrocurva* was the third most common cladoceran in all but the first Davis (1954) study. In the two Davis (1954, 1962) studies and the present one, this species peaked from June through August. The Rolan *et al* (1973) data are not precise, giving only sporadic ranges of concentrations, but they imply *D. retrocurva* maintained a rather high population level through November.

The seasonal abundances of adults of 2 cyclopoid copepods also differed among the 4 studies. *C. americanus* (*C. vernalis*) was apparently not very abundant in 1950–51, although it was most common in July and September (Davis 1954). Davis (1962) encountered *C. vernalis* only in October. This species was more abundant during 1971–72 (Rolan *et al* 1973) than in 1973–74. It fluctuated wildly in summer during the former study and declined markedly from June to August 1973. *T. prasinus mexicanus* was not encountered in 1950–51 (Davis 1954); however, it was known to occur in Lake Erie (Chandler 1940). It was present throughout the sampling period in low numbers in 1956–57 (Davis 1962). Rolan *et al* (1973) found it in greater concentrations than did the present study, with its distribution similar to that of *C. vernalis*. In 1973–74 its population had increased some by August from its low winter-spring level; its meager maximum occurred in November.

It is tenuous at best to contrast concentrations of zooplankton among studies conducted by methods that are not comparable, as is the case here. Nevertheless, Rolan and co-investigators' (1973) comparison of population maxima can be expanded to include the present study. Based on peak concentrations of total cladocerans and total copepods (excluding nauplii which Rolan *et al* (1973) did not count), it appears that Rolan's basic conclusion is still valid: that zooplankton increased in abundance between 1951 and 1956 then stabilized at rather high levels.

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